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FINITE ELEMENT MODELS FOR THE SUPPORTABILITY OF USAF AIRCRAFT STRUCTURES

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ASTRON RESEARCH AND ENGINEERING HAS ASSESSED THE FEASIBILITY OF IMPLEMENTING A USAF-WIDE DATABASE OF FINITE ELEMENT MODELS FOR THE SUPPORTABILITY OF STRUCTURES OF USAF AIRCRAFT. THIS STUDY INCLUDED: (1) AN EXAMINATION OF VARIOUS AIR FORCE ORGANIZATIONS AND THEIR CURRENT METHODS AND REQUIREMENTS FOR FINITE ELEMENT MODEL DEVELOPMENT, ANALYSIS, AND DATA TRANSFER, (2) A SURVEY TO ASSURE THAT ADEQUATE SOFTWARE IS AVAILABLE WHICH MAY BE USED FOR THE DEVELOPMENT AND OPERATION OF A CENTRALIZED FINITE ELEMENT DATABASE, (3) A DETERMINATION OF THE REQUIREMENTS OF THE SOFTWARE AND SOFTWARE INTERFACE TO BE USED FOR CREATING THE DATABASE, AND THE USER INTERFACE FEATURES IT MUST INCLUDE, AND (4) A METHOD TO IMPLEMENT THE DATABASE TO ASSURE ITS LONGEVITY AND CONTINUED EFFECTIVENESS. Keywords:

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1. INTRODUCTION

The application and utility of finite element models extends throughout an aircraft's life cycle from its early conception throughout its development, test, production, and operational deployment. These models must be accessed by various Air Force organizations in order to address a variety of structural design criteria during each of these stages. The widespread usage of finite element models by numerous organizations which perform analyses on a wide range of applications has facilitated the aircraft design and analysis process by reducing the dependence on costly and time-consuming hardware test procedures. However, it has also resulted in the widespread proliferation of finite element models such that they are difficult to manage on an organizational scale.

Among the key organizational issues pertaining to the management of finite element models are the accessability and transportability of these models among the various groups, organizations, and functions which require them. These issues are complicated by differences in geographic location, computing machinery, finite element modeling and analysis software, analysis requirements, model fidelity, and other specific applications. The combination of these factors results in organizational inefficiencies which include duplication of effort, inappropriate analyses, miscommunication, and increased costs throughout the aircraft life cycle.

In an effort to alleviate the organizational problems associated with the management of finite element models, the Air Force Wright Aeronautical Laboratories (AFWAL) has determined that it is necessary to examine the feasibility of implementing a database of finite element models which can facilitate the transportability and accessability of finite element data among the various organizations which require them. This database can comprise a central repository for finite element data which can be made available throughout the Air Force. The advantages of the database approach include decreased costs over the aircraft life cycle, increased engineering efficiency among the various organizations which use finite element data, better communication among these organizations, higher quality models and analysis results, and an enhancement of competition among Air Force contractor organizations.

The objective of this Phase I SBIR program was to assess the feasibility of developing and implementing a centralized database of finite element models for the supportability of aircraft structures, which can be accessed by various organizations throughout the Air Force. In support of this objective, Astron Research and Engineering has studied the applications of finite element modeling and analysis throughout the aircraft life cycle, including various organizations within the Air Force who use finite element data during these life cycle stages. These studies were then used to devise functional requirements for a centralized database of finite element models, and implementation objectives for use of this database throughout the Air Force. The results of these studies are discussed below.

2. APPLICATIONS OF FINITE ELEMENT MODELS IN THE AIR FORCE

A brief review of finite element model usage over the life cycle of an aircraft is given to demonstrate the wide application of these models, and the need to retain, access, and transport finite element data among the organizations which need them. This review is necessary in order to develop requirements for the centralized database so that it properly addresses the technical needs of the user community during each stage of the aircraft life cycle. For the purposes of this discussion the life cycle of an aircraft can be considered to be an acquisition cycle and an operational cycle. The applications of finite element models will be discussed in the traditional sequences of the phases in each of the cycles.

The acquisition cycle normally consists of five phases as defined in AFR 57-1. These include the conceptual, demonstration and validation, full scale engineering development, production, and deployment phases. Throughout all phases of the aircraft acquisition cycle, the Air Force reviews aircraft design criteria and requirments through a design review process. This process is necessary to ensure that the aircraft prime contractor is continually complying with contract design and performance specifications. The contractor may use drawings, reports, analysis or test results to show that design criteria are being satisfied. In most cases, the aircraft prime contractor is responsible for the finite element models developed, and does not necessarily deliver these models to the Air Force for review, although finite element modeling and analysis may have been specified tasks in the product development contract. The Air Force therefore depends on the judgment of the contractor that finite element models and their results are valid and accurate. If necessary, the Air Force may instigate parallel studies to validate contractor finite element models and analysis results.

The conceptual phase begins after a requirement for a system has been identified through the Operational Requirement Process (AFR 57-1). During this phase the tasks are directed towards identifying and exploring alternative solutions or concepts. Inputs are provided by all participating commands to identity candidate solutions and their characteristics. The lead organization at Aeronautical Systems Division during this phase is generally the Development Plans Organization (ASD/XRH). This office, working with the Secretary of the Air Force, Directorate of Advanced Programs (SAF/AQQ), and the Air Force Laboratories, narrows the set of alternatives so that additional conceptual studies and analyses can be conducted through contracts with industry. The concepts studied prior to contract initiation include in-house parametric designs submitted during pre-proposal activities. The Design Analysis Directorate (ASD/XRH) has the task of determining the feasibility of the early conceptual solution and writing a credible Request for Proposal (RFP) for development of the aircraft. This RFP must assure the best resulting product for the Air Force which capitalizes on the latest technology, while minimizing costly risk in the development program.

The analysts in the Design Analysis Directorate of Development Plans (ASD/XRH) view finite element models on existing aircraft as being an effective tool to improve conceptual estimates. They can use the models to make more realistic extrapolations from analogous designs of aircraft sections, such as a wing carry-through box with a pivoting wing. Accurate weight estimates and load distributions contribute to reduced development costs as they can prevent late design changes to accommodate the early over-optimistic aircraft weight predictions.

The contractors performing the conceptual studies will develop finite element models commensurate with their needs for their concept. Preliminary design activities involve the evaluation of a number of design alternatives in order to most cost effectively satisfy design and cost objectives. Consequently, it is necessary to maintain versatility at each stage of the preliminary design process, since the entire design concept is subject to change. Preliminary structural analysis activities may include the creation and analysis of coarse to medium fidelity finite element models. These models are used to determine the magnitude of applied loads, define the initial structural member sizing, and assess the structural mass, stiffness and strength of the airframe. From these studies, the design concept is further refined, and additional structural design criteria are derived.

During the demonstration and validation phase, the designs and selected candidate solutions are further refined through continued extensive studies and analyses, hardware development, and possible tests and hardware evaluations. It is during this period that the design responsibility begins to transfer to the Systems Program Office (SPO) which will continue the task with the support of Development Plans, the AFWAL, and other Air Force laboratories. The objective of this phase is to make the decision to proceed into the full scale engineering development phase (FSED) on a selected concept, in which the FSED contractor develops more detailed designs of the aircraft system with the intended output being, as a minimum, a preproduction system that closely approximates the final product.

As the design iterates towards the final product, finite element models are further refined to address additional sets of requirements. These requirements pertain to the detailed design of structural members, life prediction and durabilty assessment, and the development of test plans and structural verification experiments. These activites require the use of high fidelity finite element models, which are often qualified and correlated with test data. Depending on the application, these models may significantly reduce the aircraft development effort, since contractors may use analysis results, as opposed to expensive and time-consuming hardware tests, to show that structural design criteria are being satisfied. As each of these criteria are satisfied, the aircraft structural configuration becomes more detailed. The design then proceeds onto the critical and final design stages, in which a preproduction design is developed. The preproduction design can be used during the operational test and evaluation phase, which is generally a prerequisite to the production decision.

Before the operational test and evaluation phase (OT&E) begins, contractors demonstrate the basic flying qualities and performance of the aircraft through flight tests, generally at the Air Force Flight Test Center, (AFFTC), Edwards AFB, California. The AFFTC is the responsible organization for the support of the contractor demonstration flight tests. They assist the SPO and the contractors in planning the flight test profiles, the instrumentation, data collection, range support during the tests, and post flight analyses. The AFFTC personnel have uses for finite element models since they can contribute significantly by reducing the time required for the AFFTC test personnel to understand the new aircraft, to be able to calculate load paths through the aircraft, and to provide better testing recommendations to the contractor on flight test profiles and instrumentation requirements.

Flight test data are used by the contractor to verify the analytically predicted flight performance of the structure and to refine the finite element models. The models may be altered to better correlate with flight test data, to better define specific operational conditions, or to address required structural design modifications determined during test. As the models gain additional detail and more accurately simulate the structural behavior of the operational test vehicle, analytical activities gain additional confidence. It is therefore possible to apply reliable and cost effective analytical methods, as opposed to experimental methods, to show that additional structural design criteria are being satisfied.

The OT&E is a test of the complete weapon system including all supporting equipment. This test is conducted in as realistic an operational environment as possible to estimate the prospective system's military utility, operational effectiveness and operational suitability. The OT&E may be performed by various organizations, and the data obtained can be used to continually update the finite element models of the structure so that more accurate analytical assessments can be made. Additional analyses may be required to address different operational conditions or structural modifications, and/or to further optimize the structure. Finite element models must therefore be modified or created as required.

The operational cycle begins with the deployment phase whereby the management of the aircraft structure becomes the responsibility of the Air Force Logistics Command. The deployment phase encompasses the delivery of an acceptable integrated system to the using and supporting commands. When the Program Management Responsibility Transfer (PMRT) occurs, the aircraft weapon system is assigned to an Air Logistic Center (ALC) and the management of the structure resides at that ALC during the operational life. Inherent in the PMRT is the transfer of responsibility for the Aircraft Structural Integrity Program (ASIP, discussed below) from the Air Force System Command (AFSC) to the AFLC. This entails a transfer of the finite element analysis capability including the models and associated data. To facilitate the efficient transfer of responsibility, the models must be complete and in a format immediately useful to the recipients.

When an aircraft is placed in the Air Force inventory, it may remain operational for twenty to thirty years. During this period, the ALC and other Air Force organizations will perform a number of activities that invoive finite element modeling and analysis. These activities include the evaluation of structural design criteria to determine new mission capabilities (new requirement alternatives previously addressed), stores compatibility, rapid battle damage repair, accident investigations, structural repair, aircraft structure life extension, and new materials evaluation. Each of these activities requires finite element models with various degrees of detail for adaptation to a wide scope of applications. If models are not accessible to the responsible Air Force organizations, they must be purchased from the aircraft contractor.

During the operational cycle, the Operational Commands and Headquarters USAF continue to perform Mission Area Analyses (per AFR 57-1), whereby existing deficiencies may be identified in the structure. These deficiencies may arise from a change of mission, change of threat, development of a new weapons system, or an obsolescence of an aircraft due to age. In some cases, the deficiency may best be solved by modifying an existing aircraft to perform the new mission through the addition of a new store, modification of the airframe for a longer life, the strengthening of the airframe to withstand the new mission or tactic, or the installation of a new weapons system. The Headquarters Air Force Logistics Command currently lists in excess of twenty major modifications to operational aircraft that affect the structure. Depending on the type and extent of the modification (i.e. major modifications verses Class II modifications), various organizations may have responsibility for the creation or modification of finite element models to examine structural design criteria. These organizations may include various groups within the Air Force, or a contractor (which may or may not be the prime contractor for the aircraft).

The discussion on the applicability of finite element models thus far has followed the activities in the sequence of phases in the aircraft life cycle. There are also numerous applications of finite element models which occur continually during the development and operational cycles of an aircraft. These applications include the assessment of reliability and maintainability, stores compatibility and certification, and technology base development.

Reliability and maintainability are considerable life cycle cost drivers. Early in the life cycle, considerations are given to the aircraft structural integrity and its maintenance throughout its operational life. The Aircraft Structural Integrity Program (ASIP), directed by AFR 80-13, has the objective to assure the structural integrity of aircraft structure, including airframe strength, rigidity, damage tolerance, durability, and economic life. Aircraft structures are analyzed to determine damage tolerance as a function of specified mission profiles, flying time, and other operational measureables, such as landings or weapon deliveries (e.g. dive bomb runs). These analyses will determine the minimum inspection interval for the aircraft and its maximum predicted utility, and can be used to modify the structure to increase its durability and reduce its inspection frequency. The ASIP can greatly reduce the aircraft life cycle cost, increase the aircraft combat availability, and enhance its safety. ASIP requirements are included in the procurement documentation for each aircraft and considerations for the ASIP are included in each development phase from conceptual through production. The ASIP is updated to include any structural modifications to the aircraft or changes in mission which may occur during its operational life.

Finite element models have broad application in the ASIP program. Typically, the aircraft prime contractor is responsible for the models and analyses, although various Air Force organizations may use these models to perform specific analytical tasks. The models used for these studies must be highly detailed in order to properly describe the stress field in the component of interest. As a result, it is often necessary to refine existing finite element models, or create new models to adequately support these studies. Generally, stress results obtained through finite element analyses must be post-processed with a variety of stand-alone programs to further assess crack initiation, crack growth, or fatigue life.

Stores compatibility and certification is a repeated effort throughout the aircraft life cycle to address mission changes, added capabilities, or the introduction of new weapons to the Air Force inventory. The Aircraft Compatibility Office (Seek Eagle) analyzes the aircraft-store compatability, and certifies these combinations prior to flight testing. Finite element analyses must be conducted on aircraft systems with stores since these stores may alter the structural characteristics of the system. Typically, high fidelity models are used for structural dynamic and aerodynamic analyses to determine the structural integrity of components under various operational conditions. It is often necessary to adapt finite element models provided by different contractors (i.e. the aircraft prime contractor and the store contractor) to perform these studies.

The technology base provides the capabilities to support current systems and to address the technical needs of future systems. The Air Force Systems Command (AFSC) represents the laboratories that contribute heavily to aircraft structures technology development, and maintain centers of excellence that provide support to other Air Force organizations throughout the aircraft's life cycle. Among its multiple areas of technical responsibility, the AFSC Flight Dynamics Laboratory performs analytical and experimental programs to validate advanced structural design concepts, to investigate payoffs of new design concepts and materials usage, and to develop the technology base in structures. Each of these activities requires the use of finite element models of various levels of detail. For example, structural optimization codes allow aircraft designers to minimize structural weight of the aircraft system, while maintaining structural design criteria. This capability would not be feasible without the use of finite element analysis. Although this capability may be initially developed with simplified representative models, finite element models of real operational aircraft are often needed to validate the new technical capabilities under practical conditions.

As described above, finite element models are used throughout the aircraft life cycle. These models provide an efficient means by which structural design criteria can be verified, thereby reducing the dependence on costly and time-consuming hardware tests. In order to develop the technology base which allows the application of finite element analysis to be a useful tool during the product development and operational cycles, it is also necessary to validate new technologies with finite element models. As new technologies evolve, finite element methods will allow for the more efficient design and development of aircraft structures, and will continue to have widespread application throughout the aircraft life cycle. The use of finite element techniques and models will therefore increase as new applications are developed.

A centralized database of finite element models can promote the efficient use of finite element methods, and allow for the efficient access of finite element data by the various organizations which need them when they are needed. Currently, there is no standard procedure within the Air Force by which finite element data may be obtained by the various organizations. This creates a condition whereby highly advanced capabilities may exist for these organizations to perform their technical tasks, however, due to lack of data in the proper form, the advantages of this technical base are potentially lost. Aircraft development and operational costs may increase, since technical tasks may not be performed with the most efficient methods, or may be performed with less than desirable methods. It is therefore necessary to examine the organizational management of finite element models by the various Air Force organizations to determine the areas for potential improvement through the application of a centralized database.

3. ORGANIZATIONAL MANAGEMENT OF FINITE ELEMENT MODELS

Key individuals in a number of Air Force organizations were contacted to determine the extent to which finite element models are used, and the methods by which these models are managed within and among organizations. These organizations represented a cross section of those having the capability to perform finite element analyses, and those who require finite element data to accomplish their tasks. These organizations cover the activities required across the aircraft life cycle. Specifically, the following Air Force organizations were contacted:

- o Wright-Patterson AFB (AFWAL), Ohio
  - * Flight Dynamics Laboratory
  - * Aeropropulsion Laboratory
  - * Aeronautical Systems Division
    - Development Plans
    - Systems Engineering - Survivability
    - 4950th Test Wing
  - * Headquarters Air Force Logistics Command (AFLC)
    - Weapons System Master Plans
    - Major Aircraft Modifications
    - Packaging Evaluation Agency

- Air Logistics Centers
  - Warner Robins AFB, Georgia
  - Hill AFB, Ogden, Utah
  - McClellan AFB, Sacramento, California
  - Kelly AFB, San Antonio, Texas
  - Tinker AFB, Oklahoma City, Oklahoma
- Armament Division, Eglin AFB, Florida
  - 3246 Test Wing
  - Aircraft Compatiblity Office (Seek Eagle)
- Air Force Flight Test Center, Edwards AFB, California
- Inspector General, Norton AFB, California

The primary objective in our discussions with these organizations was the examination of current organizational procedures for the management of finite element models, and the possible applications of a centralized database of models within these organizations. Although the scope of activities among these organizations varies considerably, a centralized database must be adaptable to each of their respective needs. Therefore, the requirements for any centralized database of finite element models must address the aggregate needs of the user community. General findings concerning the source, acquisition, use, storage, communication and transport of finite element data are discussed below. These findings may or may not apply across the board to specific organizations, depending on their specific applications of finite element data.

The sources of finite element models for these organizations are primarily the aircraft manufacturer. Typically, the Air Force does not require the delivery of finite element models in a standard format in the product development contract. Therefore, certain Air Force organizations are required to obtain or create these models when they are needed to address specific analysis reqirements during various operational stages. Over the life cycle of an aircraft, the identical finite element model of an aircraft system or component may have been purchased from the contractor several times by different organizations, even though the development of this model may have been initially funded by the Air Force under the product development contract. On some occasions, it was found that the Air Force is prohibited from accessing finite element data and/or performing analyses through limited rights clauses imposed on this data. Since the Air Force does not own this data, finite element models may also be repurchased from the contractor several times with only minor changes. The lack of a configuration controlled set of finite element data available to various Air Force organizations at the time the aircraft is placed in the inventory results in organizational inefficiencies which may increase the operational costs of an aircraft.

Finite element models which are obtained from Air Force contractors are subject to typical government contracting procedures, in which the contractor must respond to a Statement of Work to deliver the model. The Air Force may need this data within a scheduled time frame in order to support key technical decisions which properly consider the various technical alternatives. To reduce lead time in acquiring these models, and thereby increase analysis time to examine design alternatives, finite element models must be readily available. The necessity, time, and cost of procurement of finite element models from Air Force contractor organizations may be prohibitive. These activities restrict the application of finite element analysis by Air Force organizations, and may indirectly increase product development and operational costs.

When models are obtained from the aircraft manufacturer, they typically lack adequate documentation which will aid the analyst in understanding the models so that he may perform his specific study. The extent of the model documentation is currently at the discretion of the aircraft manufacturer. The Air Force generally does not require the aircraft manufacturer to provide a standard set of documentation which can be used to judge the adequacy of the model and its analysis results. The responsible analyst must therefore spend considerable effort in understanding the model and/or performing analyses to ensure the adequacy of the delivered model. In many instances, he must also locate the responsible individual who created the model within the contractor organization to completely understand the model and its results. The lack of standard and concise model documentation may therefore impede current and future studies, cause unwarranted delays, promote inappropriate analyses, and support invalid conclusions, if the model and its documentation are misunderstood.

Air Force organizations and aircraft manufacturers generally use different finite element modeling and analysis software, installed on different computing machinery. It is therefore difficult to specify a single format for the delivery of finite element models. The Air Force organization receiving the model may need to convert the delivered finite element data to a format that can be used on site. If format conversion is required, the responsible analyst may spend weeks attempting to understand the finite element data, and developing the software necessary to properly convert the model to a useful format. This is especially true if the analyst is not familiar with the finite element software used by the contractor. Format conversion can be a lengthy process, since the model must be properly qualified to ensure the integrity of the resulting model before it is used for other applications. This is done by performing many modeling checks and analyses to match the analysis results obtained by the contractor. If qualification procedures are not adequate, the analyst may inadvertantly perform analyses on an invalid or uncorrelated model. The use of different computer hardware and software among Air Force and contractor organizations, although impossible to control, is a further restriction on the applicability of finite element models.

Finite element models are typically acquired for a specific purpose and are generally managed by a single individual within an Air Force organization. This individual may use his own software for converting the model format, and implement his own procedure for qualifying the model. He may then modify the model to suit his specific needs, and perform an analysis. When he has completed the study, the analyst typically is responsible for storing the model on tape, and maintaining the model documentation. Throughout the Air Force, many different individuals use finite element models to address many different applications. It is therefore difficult to locate these individuals and maintain awareness of their activities. If finite element models are needed, it is typically necessary to contact the individual(s) responsible for the models within an organization, causing a condition whereby there are possibly numerous sources of finite element models within the Air Force. Since the aircraft life cycle may last several years, the individual originally responsible for the finite element model may no longer be a part of the organization, requiring considerable re-learning by the responsible analyst. The lack of a standard mechanism for sharing finite element data can can result in increased costs through the duplication of effort, the repurchase of finite element data from a contractor, or the application of less than desirable approaches to the solution of certain problems.

Certain organizations lack the personnel, software, computing machinery, and/or budget to perform extensive finite element modeling and analyses, however, if this data were readily available, it could better serve the technical needs of their programs. For example, the packaging of aircraft components for shipment by the ALC does not currently employ extensive finite element analyses, and must therefore rely on expensive and time-consuming hardware tests. Finite element data may be used by the package designer to gain further insight on the structural behavior of the item which must be packaged, and facilitate the development of testing procedures. Finite element techniques may also be employed to optimize the design and weight of the packaging material itself, resulting in higher quality package designs and lower shipping costs. This is only one example out of the many possible applications of finite element data by organizations which are off-line from the primary aircraft development effort. Various other organizations and activities may find additional uses of finite element data if this data were readily available.

The management of finite element models throughout the Air Force appears to be driven by the applications which access these models. This is exemplified by the fact that each user requires finite element models with the minimum detail to satisfy his immediate problem and formatted to operate on the computers and software available within his organization. The many specialized uses of finite element models by geographically separate organizations that have specialized uses for them has caused a wide proliferation of finite element models throughout the Air Force, such that they are difficult to efficiently and economically manage across organizations. This has led to considerable duplication of effort, inappropriate analyses, miscommunication, and increased costs over the aircraft life cycle. Although a centralized database of finite element models cannot address all of the problems associated with the organizational management of these models, it can introduce an environment and mechanism by which these problems may be alleviated. As management methods are improved in the acquisition and application of finite element models across Air Force organizations, considerable benefits in efficiency, expediency, and costs can be realized.

4. APPLICATIONS OF A CENTRALIZED DATABASE

The use of a database as a central repository for finite element models which can be accessed throughout the Air Force respresents a fundamental change in approach to the management of these models. Currently, considerable emphasis is placed on the management of the applications software which use this data (e.g. finite element modeling and analysis codes, computer programs, etc.), however, little or no emphasis is placed on the management of the data itself. The database approach recognizes that the management of finite element data is also a necessary function to ensure engineering efficiency throughout the aircraft life cycle. The possible applications of such a database are discussed below.

A centralized database of finite element models can have wide application during the aircraft development cycle. If finite element models were required from the aircraft prime contractor in a standard format with standard documentation for delivery at each stage of aircraft development, the Air Force could benefit by obtaining better abilities to perform technical monitoring and program management tasks during each stage of aircraft development. Access to these models would allow the Air Force to examine in detail the finite element modeling assumptions and the quality of the analyses performed by the contractor. Consequently, the contractor may put more effort into the development of these models, thereby increasing the technical quality of analyses performed. The Air Force may also obtain greater control over the technical direction of the aircraft development program, taking a more active role in the evaluation of structural design criteria.

A centralized database could contain a complete set of finite element models developed during the various stages of aircraft development which can be used as a historic database of technical data. This database can add further insight to the technical direction of the development program, and be used for guidance in making future technical decisions. The technology base required for the support of current and future aircraft can be improved through the evaluation of lessons learned throughout the development programs of similar aircraft. This would allow for the better technical planning and assessment of technical risks when new aircraft, or new derivatives of aircraft, are being investigated.

During the aircraft operational cycle, a centralized database can facilitate the transfer of finite element data across Air Force organizations. If finite element models and documentation were obtained from the contractor and stored in a database when the aircraft is placed in the inventory, this data could be readily available to all Air Force organizations when it is needed. Procurement lead time and costs can be reduced, since the Air Force would be relieved from having to purchase finite element models from the contractor several times over the life cycle of the aircraft. Since this database would be centrally located, the various organizations which need finite element data could communicate with only one source, as opposed to the numerous sources which are currently relied upon. The impact of organizational changes on the finite element data acquisition process would also be minimized as a result.

A centralized database of finite element data would allow the Air Force to better evaluate structural design criteria before decisions are made to commit development funds towards certain activities. If enhancements or modifications to the aircraft system are necessary, technical specifications and performance criteria could be better stipulated to competing contractors in the Request for Proposal, allowing for reduced development costs. In many cases, finite element data for components which are being considered for modification are currently the property of one of the contractors. Portions of this data are often necessary for dissemination to the entire contractor community to promote open competition. The availability of this data to the Air Force in a centralized database would allow the Air Force to perform analyses and selectively disseminate the needed information to the contractor community, thereby reducing the reliance on the single contractor which owns the information. When an implementation contractor is selected, the Air Force could supply the needed finite element data, relieving the contractor from subcontracting to a third party to obtain this information.

The applications of a centralized database of finite element models discussed above are the result of only a cursory examination of finite element usage throughout the Air Force over the life cycle of various aircraft. When such a database is eventually implemented, numerous other applications may become evident. The design of such a database should consider each of these applications in the development of database performance requirements.

5. CENTRALIZED DATABASE REQUIREMENTS

A number of requirements must be imposed on a centralized database of finite element models to ensure its applicability to various Air Force organizations over the many years in the aircraft life cycle. Of primary importance is the fact that the centralized database must continually address an evolving set of user needs throughout its forseeable lifetime. Therefore, the centralized database must have built-in versatility to be applied to new applications and new technological advances as they occur. This versatility applies to new developments in finite element modeling and analysis software, database software, graphics capabilities, computer hardware or other peripherals. Versatility can only be accomplished through the careful development of database requirements in the preliminary planning stages.

One of the fundamental requirements of the finite element model database is the storage of data so that it can be selectively and efficiently accessed. This requirement implies that the database should be located on a central computer at a centralized location, such as AFWAL, allowing many users to either access the database directly on site, or remotely through high speed data transmission lines. The central computer does not necessarily have to be a single computer, since future trends in database management include the development of distributed databases which may reside on different computers, accessible via network. The location of finite element data at a central location will minimize the need for users to communicate across organizations. Users would therefore have a single source and a standard procedure by which they may obtain finite element data. Technical support of the database would also be minimized if it were centrally located.

Since the various Air Force organizations have particular requirements for the evaluation and application of finite element data, it is necessary to incorporate a database schema which is easily interpreted by the user community. The database schema is the method by which the data is represented in the database. In an open database architecture, it is necessary to allow users the ability to retrieve that information which is most useful to them in the form that is most useful to them. This ability will facilitate the transfer of finite element data among organizations which utilize different applications software (e.g. finite element modeling and analysis software, computer programs, etc.), and facilitate the development of new applications which use this data.

The centralized database must allow for the manipulation and presentation of data so that it can effectively support the user community and promote data sharing. This implies that the database will incorporate a consistent, user-friendly, menu-driven interface to allow users to view and manipulate data in the formats which have meaning to them with minimum training. In terms of hardware, graphics and terminal drivers should support the existing installed base of computer hardware and peripherals, as well as maintain versatility to support additional new hardware capabilities as these become available. In terms of software, the database should support finite element formats and other applications which are currently being used by the Air Force, as well as maintain adaptability to additional new software capabilities as they are developed.

The database should also protect data to ensure its security, reliability, consistency, and correctness. Models which are initially stored in the database should therefore be subject to some standard qualification procedures to ensure that the models will be operational when delivered to the end user. While resident in the database, the models should not be allowed to be modified by users without proper authority. Furthermore, the database should guard against unauthorized access to classified or proprietary data.

In order to facilitate its implementation, the database should utilize existing software whenever possible, and be adaptable to a variety of machines. The use of an existing database management system, executive system, user interface and database schema allows for lower development, operational, and maintenance costs over the lifetime of the database, since the support of these components will be the responsibility of various third party private vendors and/or government organizations. Machine independence is also a key requirement due to the evolving nature of computer hardware. The database should therefore be implemented with an operating system which allows for the installation on various computers, such as UNIX.

The above requirements define the direction for database development and implementation activities, from which detailed specifications for the database software can be derived. At this early stage, no attempt is made at defining the detailed specifications since the database architecture has not yet been finalized. A database architecture must therefore be developed which satisfies each of the above requirements in order to be fully operational.

6. CENTRALIZED DATABASE ARCHITECTURE

A suggested means by which a centralized database of finite element models can be made available for dissemination throughout the Air Force is shown in the schematic diagram in Figure 6-1. This database architecture incorporates a modular design, allowing for the addition of new capabilities with minimum impact on existing ones. The salient feature of this database architecture is the definition of two separate databases, one of which includes only information about the models, the other, the models themselves. This dual database architecture is at the heart of the centralized finite element database proposed for implementation by the Air Force. Essentially, the information database acts as a central catalogue containing certain information which will aid the user in making decisions to either adapt all or part of an existing finite element model to his particular application, or build his own finite element model. The model database acts as a central repository of finite element models which can be accessed as a library by users throughout the Air Force. The dual database architecture is advantageous over a single database containing only finite element models with regard to the model identification and selection process, computer system on-line resource requirements, and data security. These advantages and additional capabilities of the suggested database

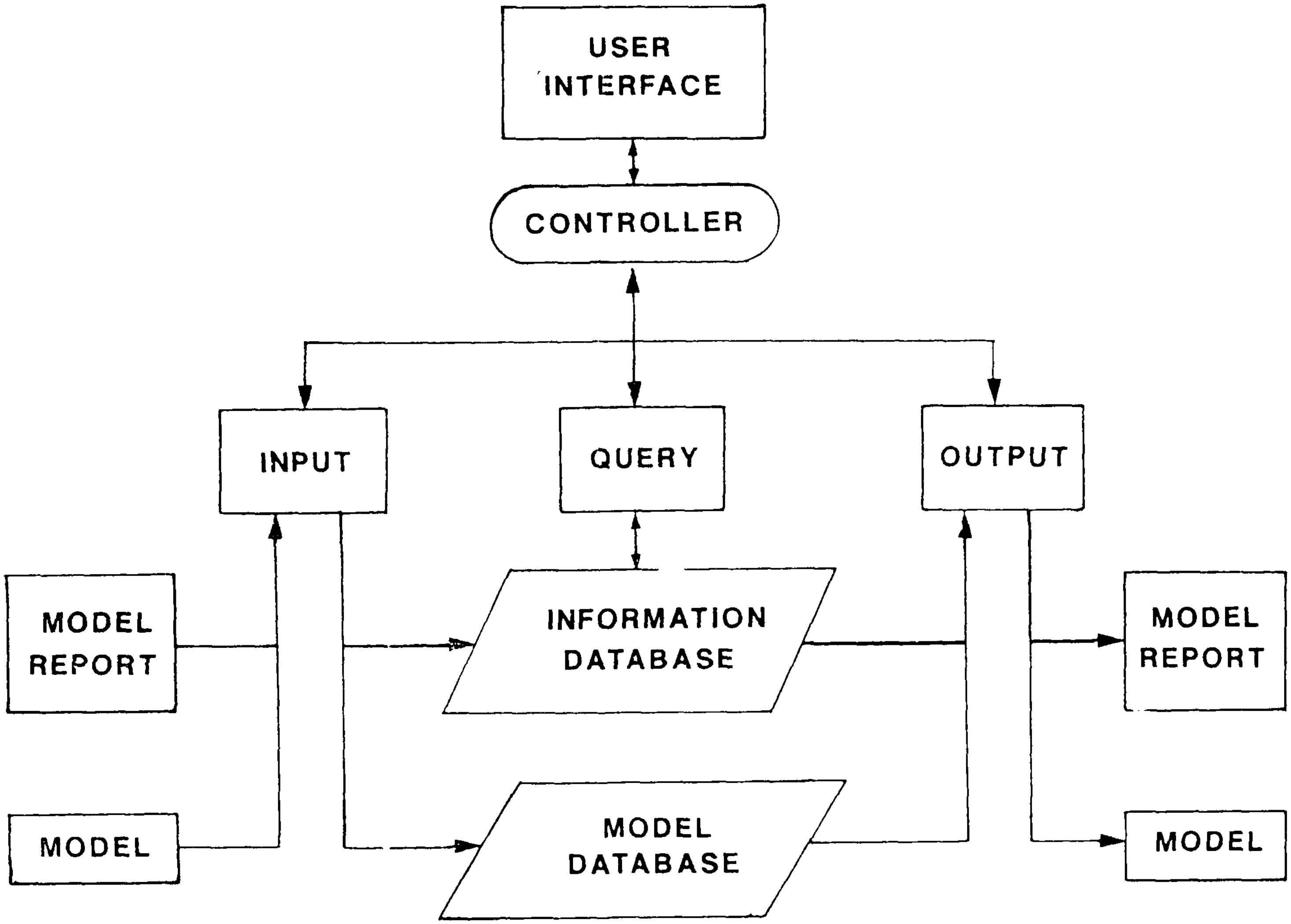

Figure 6-1. Database Architecture

architecture are discussed below.

The finite element model identification and selection process with a single model database would be cumbersome since database users would have difficulty in identifying the particular models which are of interest to them. Users would be required to examine individual data records within the models, and/or load the models locally for further examination. Moreover, the finite element bulk data deck does not necessarily contain sufficient information to fully describe the model, since a large amount of information about the models cannot be extracted through the examination of the models alone. This information includes descriptive data (e.g. product data, mass, application, material identification, etc.), analysis data (e.g. type of model, type of analyses conducted, rationale for model configuration, etc.), or other identifiers (e.g. creation date, drawing references, owner, revision number, etc.) A dual database archictecture streamlines the model identification and selection process since the information database would provide only summary and catalogue information that could be used as criteria for model selection. Consequently, users could examine many different finite element models and many more modeling alternatives before down-selecting to the appropriate finite element model.

A single model database would require the on-line storage of each data record for all finite element models. This would be necessary since database users would be interacting directly with model data for identification and selection purposes. The extensive amount of on-line information required to retain all models within a single model database would have penalties associated with system resource requirements. In particular, a large amount of disk space would be required for storing the models, and the system central processor could be overloaded due to possibly large numbers of users performing extensive search and/or extraction operations on possibly large numbers of models. The effectiveness of a centralized database consisting of on-line model data would therefore be closely tied to the type of computer system on which it was installed. In this event, growth of the model database would also require growth of the computer system. A dual database architecture would minimize system resource requirements since users would be interacting with the smaller subset of data in the information database. Problems associated with extensive on-line storage and processor requirements are alleviated since the larger model database can be stored off-line in a library (i.e. on tapes or other mass storage media), to be loaded only when models are requested for delivery to the user.

In the event that users were interacting with a single model database, it would be difficult to protect proprietary or classified data which may be written into the finite element model bulk data deck. A dual database structure is not a panacea for all model security issues; however, since users will be interacting only with data about the models in the information database, it is possible to protect proprietary or classified data to some extent. An information database can be configured which will allow users to view only that data which has been cleared for dissemination throughout the finite element analysis community. If sensitive information is contained in the finite element bulk data deck, this information can be password protected, or the user could be alerted to this fact, and be given the identification of the appropriate point of contact to properly clear this information in the event that additional model details are necessary.

The dual database structure consisting of an information database, on which interactive operations could be conducted, and a model database, which consists of an off-line library of finite element models has numerous other advantages over a single model database architecture. It is anticipated that the information database will be an industry standard relational database, such as ORACLE, which incorporates SQL (Structured Query Language). SQL is a non-procedural, unified language which allows users to easily define, access, manipulate and control data in the database. The information database will also utilize an industry standard logical data model, such as the Air Force IDEF model. The IDEF methodology provides a systematic approach for analyzing and documenting functional requirements and data relationships among the entries in the information database. The use of an existing relational database management system and logical data model assures compatibility, portability, connectability, and capability of the centralized database and its contents over its lifetime. The initial development and operational costs for the centralized database will be minimized since various private and government organizations are responsible for the development and operation of the database software and methodology. Configuration management of the centralized database would therefore entail only configuration management of the data entries in the database. As new capabilities arise in finite element modeling and analysis, it would be possible to modify the attibutes in the information database to meet different sets of user needs.

The type and extent of the data in the information database should include both intrinsic and extrinsic attributes which can be used to uniquely identify finite element models when viewed in the context of other models. Intrinsic data is that which can be obtained directly from examination of the finite element model bulk data deck, whereas extrinsic data is that which can be obtained only from model documentation. Intrinsic data can be loaded in an automated fashion through the input module (Figure (6-1), which would take finite element models in a standard format (e.g. COSMIC NASTRAN, MSC NASTRAN, ANSYS, etc.) and extract data for deposit in the information database. The input module could also be used to automatically create a neutral graphics file which can be used to display the finite element model topology to the user through the user interface. To ensure data integrity, a one-to-one mapping of database operations would be implemented for the input of intrinsic and extrinsic data. The extrinsic data would be entered through the input module by the system operator through standard forms in the user interface. To simplify this process, it is anticipated that database users will be required to complete standard documentation available in standard forms. As users gain familiarity with the centralized database, they can input extrinsic data directly to the database through the user interface in report writer format, subject to approval by the system operator for dissemination throughout the finite element user community.

The model database will contain finite element bulk data stored off-line on tapes in a model library. To ensure data integrity, models could first be qualified by either the database user or system operator before entry into the model database. The qualification process could involve checks for element conectivity, coincident nodes or elements, grounding, or other standard validation procedures. It is anticipated that the finite element models will be stored by the input module into the model database in an industry standard relational format, such as IGES (International Graphics Exchange Specification) or PDES (Product Data Exchange Specification). The primary objective of these standards was to provide a consistent means by which data may be exchanged among various software and hardware systems. For finite element data, these standards are fairly complete, containing a wide range of data types which are currently used by various finite element codes. The use of an existing industry standard storage format for the model database gives the centralized database built-in versatility to a wide range of applications and maximizes data sharability among the user community. On one hand, most proprietary finite element model pre- and post-processors (i.e. PDA PATRAN, SDRC SUPERTAB, ANSYS PREP-7) currently maintain capabilities for reading and writing finite element models consistent with these specifications. Therefore, the centralized database would not necessarily need specialized software modules to communicate with these codes. On the other hand, if alternative finite element model formats are needed, users can create specialized software to communicate with the model database by adhering to the published specification. The centralized database could be made even more adaptable to new applications through modifications in the database schema and/or communication software.

The database controller and user interface modules are the primary means by which users can interact with the database. The functions of the database controller are to ensure the proper allocation of costs among database users, to maintain data security, to track user requests, and to monitor system performance. The user interface module will provide users with a set of tools by which they can have easy and controlled access to the database as well as add new applications. Initially, users should be able to perform basic functions such as querying sets of models for information and requesting the storage or retrieval of models to or from the database in various model formats. These database operations will be simplified by the use of standard forms and menus in the user interface. In order to minimize the initial development and operation of the centralized database, it is recommended that the user interface and database controller utilize existing software, such as that developed for the Air Force for the Integrated Information Support System (IISS). The IISS user interface allows users to access a very wide variety of applications on different terminals and different host computers in a uniform manner. The use of such software has advantages in that new developments in computer hardware, such as graphics devices, can be addressed by various private and government agencies, allowing the centralized database to concentrate on developments in finite element analysis.

The database interrogation process would involve a menu-driven procedure in the user interface to guide the user in the examination of finite element models. The user interface would incorporate standard forms to minimize user training and re-learning of database procedures, and a graphics driver to facilite the display of finite element model topologies. The database query module (Figure 6-1) would utilize standard search algorithms provided by the relational database management system. The user could therefore scan the entire information database to find models based on a set of product identification codes, material properties, key words, applications, or any other combination of intrinsic or extrinsic attributes which describe the model. As the user narrows his search by finding models which appear to satisfy his needs, he would be allowed to display these models at the terminal, or request delivery of the models to his location. As outlined above, only certain users will have access to certain data in the information database, subject to approval by the system operator.

The extraction of a model from the centralized database would first involve a request from the user to the system operator. This request can be checked by the database controller to ensure that the user has proper authority to obtain the model. The user request could contain delivery instructions (e.g. user name, location, required date, etc.) and format specifications (e.g. storage media, model format, etc.) which would be entered into the database controller via the menu-driven user interface. The location of the model in the model database (library) would be stored in the information database, and the system operator would retrieve and load this tape onto the computer. The output module (Figure 6-1) would then process a batch job, in which the model in the database would be converted to the proper format and copied onto tape for delivery. Model documentation, in standard forms, would also be extracted from the information database for delivery to the user. A mailing label could be automatically generated by the output module, and the entire package, including tape and documentation, would be sent to the requesting user.

The database architecture suggested above is an efficient means by which the database requirements in Section 5 may be satisfied. It is important to note that the database architecture can utilize existing computer hardware and software, minimizing development costs. Furthermore, the modular design allows for the adaptation of new hardware and software capabilities as they arise. The database architecture establishes the overall dataflow and user interaction with the database. From this architecture, it is necessary to derive additional requirements pertaining to the operation of each software module. No attempt is made at deriving these requirements, since these activities are ideally suited to the initial development and implementation phases of the database.

7. IMPLEMENTATION OF CENTRALIZED DATABASE

The implementation of the centralized finite element model database for use throughout the Air Force requires sound judgement to reduce costs and possible technical risks to the user community. Database implementation issues include its initial development, its adaptation to the user community, its operation and maintenance, and associated costs in each of these areas. The careful planning of the database implementation can ensure the longevity of the database and its continued effectiveness throughout its lifetime.

The initial development of the centralized database should consider the use of existing software and standards and address only a limited set of finite element modeling and analysis capabilities. As is often the case, many database development programs start out with very ambitious goals, requiring the extensive development of new technologies and/or the extensive modeling of a wide range of data types. As a result, development costs may increase, and the potential pay-off and justification for the database may not be immediately evident. Furthermore, the rapid technological advancements in both computer hardware and software applications may render the centralized database obsolete when it is finally introduced to the user community.

The centralized database must therefore be evolutionary, and be adaptable to an ever-changing set of user requirements as they arise. As users gain familiarity with the database, new capabilities can be introduced to the database to address their specific needs.

The most important task in the initial stages of database implementation is the determination of methods by which finite element data can be efficiently managed. Data management first involves the selection of the types and forms of data that will most effectively support the user community, and allow for the adaptation of new developments. The AFWAL Data Item Description (DID) for aerospace structures (Appendix A) should be used as a starting point for determining the basic information requirements which should be associated with finite element data. From these requirements, it is necessary to examine standardized methods for representing the data in the database to ensure its efficient access and control. The Air Force IDEF methodology should be considered for the development of the information database, and the PDES specification should be considered for direct implementation in the model database (Section 6). The logical data models employed in the information and model databases will then determine the required capabilities for the database communication software (data entry, retrieval, and interrogation). Finite element model delivery requirements and specifications as defined in the AFWAL DID can then be further refined to reflect the capabilities and information needs of the database.

The adaptation of the centralized database to the user community must consider the specific procedural and technical requirements for the use and delivery of finite element models within the respective organizations. A reasonable means for adapting the database to these organizations must therefore be implemented to ensure its smooth transition to the user community. This implementation must include the training of users, the establishment of computer accounts, the development of costing algorithms, and the addition of security features.

For new aircraft, implementation of the centralized database can have minimum impact on the management of finite element models, since organizational procedures would require minimum modification. A standard finite element model delivery specification can facilitate the implementation of the centralized database by allowing for the easy entry of these and future models into the database. The delivery of finite element models from contractor organizations should therefore follow some standard specification, such as the AFWAL DID. This DID can eventually serve as a Contract Data Requirements List (CDRL) item to ensure consistency of all finite element data from Air Force contractors. It is important to note that delivery requirements for finite element models and documentation may initially increase the cost of performing analysis, since contractors will be forced to demonstrate technical accuracy of these models. It is believed, however, that this initial cost will be justified by both tangible and intangible benefits of a centralized database which may be used over the life cycle of the aircraft.

For existing aircraft, the Air Force must selectively decide on whether a centralized database will have long term benefit to the program before conversion to the database approach is determined necessary. For older systems, a complete set of finite element data may not exist. Therefore, it may not be feasible to adapt these systems within a centralized database. On other systems which have extensive finite element data, the costs for conversion to the database approach may not be justified if the system is near the end of its life cycle, or if there is reduced demand that finite element data for this system be transported among organizations. Conversion to the database environment could entail the conversion of numerous finite element models which may be in current use. These activities may have an initial negative impact on productivity, since organizations will be required to modify certain procedures during implementation.

The operation and maintenance of the centralized database is determined largely by the amount of data in the database and the size of the user community. The costs of operating and maintaining the database are associated with hardware (computers, peripherals, communication devices, storage media, etc.), software (operating system, database, application and conversion programs, etc.), and personnel (system operator, database administrator, engineers, programmers, etc.) The database hardware must have adequate capacity to store large amounts of information, and to make this information available to a large user community. The database software must be able to support a multi-user environment, and have capabilities for expansion as additional user needs arise. Personnel must be able to support the database user community for normal activities (e.g. user requests, training, etc.), and be able to develop additional capabilities and methodologies to address new technical advances. The implementation of the database must address operation and maintenance costs from the outset, since these factors can also determine the effectiveness of the database.

A detailed implementation plan, including specifications for the development of each database module, a description of the database schema, computer software and hardware options, personnel requirements, and associated costs are described in the ensuing Phase II SBIR proposal associated with this report.

8. SUMMARY

The application and utility of finite element modeling and analysis by various Air Force organizations throughout the aircraft life cycle is currently restricted by numerous organizational inefficiencies. These inefficiencies are associated with data management in the acquisition, storage, utilization, and dissemination of these models and their results among Air Force organizations and contractors. This problem is compounded by the fact that the Air Force does not require aircraft contractors to deliver finite element models with the aircraft when the aircraft becomes operational. Consequently, there are no standard procedures or formats by which finite element models may be obtained by various Air Force organizations which need them durirg various aircraft life cycle stages. This condition has resulted in duplication of effort, inappropriate analyses, miscommunication, and increased costs throughout the aircraft life cycle.

The possible applications of centralized database of finite element models which may be accessed throughout the Air Force have been reviewed. These studies indicate that it is feasible to implement such a database on the basis of tangible and intangible benefits to the user community. These benefits include decreased costs over the aircraft life cycle, increased engineering efficiency among the various organizations which use finite element data, better communication among these organizations, higher quality models and analysis results, and an enhancement of competition among Air Force contractor organizations. This database will require contractors to deliver finite element models to the Air Force in a standard format with standard documentation during various stages of aircraft development and/or operation.

The fundamental requirements for a centralized database were examined, and it was determined that with existing technology, such a database can be implemented. A database architecture was developed which will allow users in various Air Force organizations the ability to deposit, retrieve, and interrogate finite element data in a secure environment throughout the aircraft life cycle. The key feature of this architecture is the utilization of a dual database structure to facilitate model identification and selection, to minimize computer system on-line resource requirements, and to maximize data security. Guidelines were developed for the implementation of the database, including its initial development, adaptation to the user community, and operation and maintenance. These guidelines comprise an implementation plan to ensure the longevity of the database and its continued effectiveness throughout its lifetime.

APPENDIX A

DATA ITEM DESCRIPTION

Form Approved
OMB No 0704-0188
Exp Date Jun 30 1986

1 TITLE) for Finite Element Models of Aerospace Structures	2 IDENTIFICATION NUMBER

3 DESCRIPTION/PURPOSE

This report describes the data elements and the format of the finite element models of aerospace structures to be delivered to the Air Force. This data will be used to verify the contractors structural analysis and/or to determine the effects of future modifications (or changes) to the structure or its operational conditions. It should be noted that not all the data items will be applicable to every system. The applicable items will be identified on a CDRL (DD Form 1423).

4 APPROVAL DATE (YYMMDD)	5 OFFICE OF PRIMARY RESPONSIBILITY (OPR)	6a DTIC REQUIRED	6b GIDEP REQUIRED

7 APPLICATION INTERRELATIONSHIP

The finite element data generated for verifying the structural design criteria of an aerospace vehicle (designed and paid for by the Air Force) should be be the property of the Air Force and should be delivered in a suitable and understandable form for future use. This data will be extremely valuable in assessing the integrity of the system after modifications, repairs and maintenance.

8 APPROVAL LIMITATION	9a APPLICABLE FORMS	9b AMSC NUMBER

10 PREPARATION INSTRUCTIONS

10.1 General Requirements. The finite element data supplied in response to this CDRL item must accompany a problem narrative. This narrative must include the following items:

- Configuration version.
- Identification of the documents and/or drawings from which the model was generated. Copies of these documents must be provided if they are not available to the government.
- A key diagram showing the location of the component being modeled in relation to the rest of the structure.
- A brief description of the physical phenomena being modeled.
- A discussion on the coarseness/fineness of the grid selected.
- A rational explanation for the elements selected for the model.
- An explanation of the boundary conditions.
- Materials - Identification of the Mil Standard from which the mechanical properties were derived. Reasons for any deviations from the standard properties.
- A complete description of the flight maneuvers for which the loading conditions are attributed.
- Planform used for aerodynamic analyses showing all important dimensions.

DD Form 1664, FEB 85 Previous edition is obsolete PAGE 1 OF 5 PAGES

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10.2 Analysis Data Requirements. The finite element analysis models are classified into following five categories:

I. Static Analysis Models

II. Dynamic Analysis Models

III. Aeroelastic Analysis Models

IV. Heat Transfer Analysis Models

V. Acoustic Cavity Analysis Models

The CDRL will call for the specific models required.

10.2.1 Static Analysis Model Requirements. A static analysis basically requires a good stiffness representation. However, when gravity loading or inertia relief conditions are specified, a good mass representation is also required. This mass representation must include both structural and nonstructural mass distributions. The finite element models for static analysis must consist of the following items as a minimum.

i) Geometry - (as appropriate)

Grid Point Coordinates
Element Types
Element Connections
Coordinate Systems

ii) Element Properties - (as appropriate)

Thicknesses
Cross-sectional Areas
Moments of Inertias
Torsional Constants
Fiber Orientations
Other properties as required for special elements.

iii) Material Properties - (as appropriate)

Isotropic
Anisotropic
Fiber Reinforced Composites
Temperature Dependent Properties
Stress Dependent Properties
Thermal Properties
Damping Properties
Other properties as required for special problems.

iv) Boundary Conditions - (as appropriate)

Single Point Constraints
Multipoint Constraints
Partitioning for Reduction or Substructuring

v) Loading - (as appropriate)

Static Loads
Gravity Loads
Thermal Loads
Centrifugal Loads
Other loading conditions as required for special simulations.

For buckling or nonlinear analysis additional information is required on the following items:

- How the nonlinear matrices are derived.
- The method of solution for the nonlinear problem.
- A description of the method in the case of an eigenvalue analysis.

10.2.2 Dynamic Analysis Models. The dynamic analysis models require i) geometry, ii) element properties, iii) material properties, and iv) boundary conditions as described for the static case. In addition an accurate nonstructural mass and damping representation is required. Generally five types of dynamic analysis are contemplated.

- Normal Modes Analysis or
- Complex Eigenvalue Analysis
- Frequency Response Analysis
- Transient Response Analysis
- Random Response Analysis

In the first two cases only the method of eigenvalue analysis and the frequency (modes) range of interest need be specified. For frequency response analysis the frequencies of interest must be specified. For transient response analysis the dynamic load must be defined as a function of time or must be provided as tabular values. For random response analysis the statistical nature of the input (such as PSD, Auto Correlation) and the statistical quantities of the output desired must be specified. In addition all the information on dynamic reduction and/or modal reduction must be specified.

10.2.3 Aeroelastic Models. An aeroelastic analysis requires mathematical models of the structure and the aerodynamics. The structure is generally represented by finite element models (FEM). The requirements for the structures models are as specified under static and dynamic analysis. They include mass, stiffness and damping representation. Both structural and nonstructural mass distributions shall be included in the mass model. The aerodynamic models are generally based on paneling or equivalent methods. The requirements of the aerodynamic models are those of the panel geometry which cover all the lifting surfaces including the control surfaces, the empennage (horizontal and vertical tails) and canard surfaces. The fuselage slender body and interference panels shall be modeled to represent the flowfield adequately. The altitude (air density), mach number and other relevant aerodynamic parameters must be specified. The details of the aerodynamic theory and the limits of its validity must be clearly defined. In addition, data for the force and displacement transformations from the structural grid to the aerodynamic grid (and vice versa) shall be included in the aeroelastic models. Two types of aeroelastic analysis are contemplated. Both deal with the phenomenon of aeroelastic stability. The real eigenvalue analysis is the basis for determining the static aeroelastic stability. There are a number of methods for determining dynamic aeroelastic stability (flutter analysis), and the details of the method (references) the necessary data shall be provided with the models. Flutter analysis is generally an iterative process and can also involve more than one flutter mechanism. There are often special techniques associated with the flutter analysis, and they can be defined in terms of the ranges of the aerodynamic parameters. Such data shall be included in the aeroelastic models. In addition, provisions must be made to include the effects of the rigid body modes on the flutter model (body freedom flutter). If it is anticipated that these models will be used for aeroservoelastic analysis, then the data shall be provided for a state space formulation. Also sensor actuator locations and their range of operation and/or limitations shall be included in the data. In addition, a flight control system block diagram shall be provided with sufficient information to define all transfer functions and gains using S-domain variables for analog systems or Z-domain variables for digital systems. The units of important parameters shall be provided.

10.2.4 Heat Transfer Analysis Models. There are three elements to heat transfer models: the heat conducting medium, the boundary conditions and the heat sources and/or sinks. The data requirements of the heat conducting medium are similar to those defined for static and dynamic analysis. For instance the geometry definition includes the grid point coordinates, element types, element connections and coordinate systems. Elements can be classified into volume heat conduction and surface elements. The element type designation for the volume heat conduction element is generally derived from the degree of approximation of its shape functions. The surface elements are used to model a prescribed heat flux, a convective flux due to the difference between the surface temperature and the recovery temperature or local ambient temperature, and radiation heat exchange. Appropriate material properties, single point and multipoint boundary conditions and description of the heat sources (applied forces) have a similar correspondence in the static and/or dynamic analysis. The surface heat convection or radiation details shall be provided (through surface elements) as appropriate. The response variables in heat transfer analysis are generally grid point temperatures or the temperature gradients and heat fluxes within the volume heat conduction elements and the heat flow into the surface elements. Four types of heat transfer analysis are contemplated:

i) Linear Steady-State Response Analysis

ii) Linear Transient Response Analysis

iii) Nonlinear Steady-State Response Analysis

iv) Nonlinear Transient Response Analysis

It is often necessary to adopt special techniques for obtaining stable solutions, particularly in the last two cases. The data pertaining to these special techniques and the limitations of the nonlinear algorithms shall be fully identified.

10.2.5 Acoustic Cavity Analysis Models. Basically there are three elements in acoustic cavity analysis models: the acoustic medium, the boundaries, and the sources of excitation. The acoustic medium model shall consist of grid points and acoustic elements connecting these grid points. The response variables are generally the pressure levels and the gradients of the pressures (with respect to the spatial variables) at the grid points. So for a general three dimensional acoustic analysis there will be four degrees of freedom per node (corresponding to four response variables) in an acoustic medium model. The properties of the acoustic medium can vary with the temperature and pressure distribution and density. The boundaries of the acoustic model can be solid walls, flexible walls, openings in the walls and walls with acoustic material which can be represented as a complex acoustic impedance. For complicated boundary conditions separate finite element models may be necessary in order to derive the boundary conditions for the acoustic model. These finite element models are based on solid mechanics and their data requirements are similar to those cribed for the static and dynamic analysis earlier. The acoustic excitation source model s..all have information on the spatial distribution and the statistical properties (in terms of the frequency content) of the noise. For a deterministic case, however, definition of the forcing function includes the magnitude, phasing and frequency along with the spatial distribution. The acoustic excitation is generally given as velocity or pressure applied to the medium over prescribed surfaces or at grid points. If the disturbance is from mechanical sources, separate finite element models of the sources shall be supplied as required. These models are also generally solid mechanics models and their requirements are similar to static and dynamic analysis models. Generally three types of acoustic analysis are contemplated.

- Eigenvalue Analysis
- Steady-State Solution
- Nonlinear-Analysis

In the eigenvalue analysis the acoustic natural frequencies and mode shapes are determined. The purpose is to compare the natural frequencies of the cavity with those of the forcing function and estimate the resonance effects, and to compare the natural frequencies to the resonant frequencies of any structure which may be placed in the cavity. This analysis provides useful information for design changes in the cavity either by altering the overall dimensions or by introducing noise suppression mechanisms such as baffles or by adding noise suppression material to introduce acoustic wall impedance. This analysis does not require explicit definition of the forcing function. The steady-state solution gives the response of the cavity to a given excitation. This analysis can be in the time or frequency domain. nonlinear analysis involves an iterative solution when the properties of either the cavity or the acoustic medium vary significantly with the pressure levels and/or temperature.

10.3 Other Requirements.

The input data for all the finite element models must be provided in a format compatible with the latest government version of NASTRAN (COSMIC/NASTRAN). If the original analysis was made with another finite element program, the data shall be converted to the COSMIC/NASTRAN format. If NASTRAN does not have compatible elements or capability, the elements that are most appropriate must be identified and projections must be provided on the expected differences.

In addition to the input data a summary of output results (such as deflections, stresses, frequencies, etc. at critical areas) shall be provided for future validation of the models. Also a brief description of how these results were used to satisfy a specific design criteria. A set of undeformed and deformed plots of the structure shall be provided with all the finite element models.

*U.S.Government Printing Office: 1989 —648-056/04488